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SIGNAL STRENGTH ANALYSIS OF  
ECHO II-REFLECTED SIGNALS AT  
2 KMC/SEC (REVOLUTIONS 2000-3500)

Stephen L. Zolnay

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31 December 1965

Prepared for  
National Aeronautics and Space Administration  
Goddard Space Flight Center  
Greenbelt, Maryland 20771

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Investigation of              Tracking, Receiving, Recording and Analysis  
                                 of Data from Echo Satellite

Subject of Report              Signal Strength Analysis of Echo II-Reflected  
                                 Signals at 2 kmc/sec (Revolutions 2000 - 3500)

Submitted by                Stephen L. Zolnay  
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## ABSTRACT

This report presents a signal strength analysis of Echo II-reflected signals during recent revolutions (2000-3500). Some Echo I data from the same period are also included for comparison. The signals were cw at 2260 mc/sec reflected bistatically. Analysis of the instantaneous power level recordings shows that rapid and deep fades occur more frequently than observed previously (revolution numbers less than 2000). On some occasions fadings so severe as to present an oscillation-like appearance between noise and saturation levels have been observed. On rare occasions very low fluctuations have been observed for which an explanation is given. Fluctuations of six to ten db peak-to-peak are still present even in averaged ( $\tau = 0.1$  second) signal strength recording. Differences as large as 10 db between measured signal strength and the calculated one have been recorded sometime for periods as long as one minute. The amplitude scintillation characteristics of Echo II and Echo I reflected signals are very similar.

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SIGNAL STRENGTH ANALYSIS OF ECHO II-REFLECTED  
SIGNALS AT 2 kmc/sec  
(REVOLUTIONS 2000 - 3500)

## I. INTRODUCTION

This report deals with the signal strength analysis of Echo Satellite-reflected signals. The receiving site is the Satellite Communications Center of the Antenna Laboratory, The Ohio State University, Columbus, Ohio. The transmitting site is the Collins Space Communications Facility, Dallas, Texas. The signals originated from the latter site in the form of CW at 2260 Mc/sec, and were reflected by the Echo satellites to the receiving site. The data presented here, are representative of all data received during Echo II revolutions 2000 - 3500. Representative samples of Echo I-reflected signals during the same period are also included for comparison. The main objective of this report is to present experimental data and to describe the methods by which the data were collected with emphasis on Echo II data. This report is the continuation of an earlier effort,<sup>1</sup> and brings the information about the characteristics of the amplitude of the received signal up to date. This report and the earlier one are not only continuous but they also cover the first 3500 revolutions of Echo II. Specifically, signals obtained during the following revolutions are analyzed in this report: Echo II--2626, 2653, 2816, 3040, 3483; and Echo I--18,166 and 18,966.

## II. CALCULATED RECEIVED POWER

The theoretical received power,  $P_r$ , on an Echo link can readily be calculated from the radar range equation for a target whose scattering cross-section,  $\sigma$ , and gain,  $G_t$ , are known:

$$(1) \quad P_r = \frac{P_T G_T G_R G_t \sigma \lambda^2}{(4\pi)^3 d_R^2 d_T^2},$$

where

$P_r$  = received power,  
 $P_T$  = transmitted power,  
 $G_T$  = gain of transmitting antenna,  
 $G_R$  = gain of receiving antenna,  
 $G_t$  = gain of target,  
 $\sigma$  = scattering cross-section,  
 $\lambda$  = free space wavelength of transmitted frequency,  
 $d_T$  = range to the target from transmitter,

and

$d_R$  = range from the target to the receiver.

The transmitted power,  $P_T$ , during the passes analyzed was on the order of 10,000 watts CW. The level of the transmitted power during a pass was maintained at 10 KW  $\pm$  1 db. The gain of the transmitting antenna at the frequency of operation is 47.1  $\pm$  1 db; the gain of the receiving antenna is 42  $\pm$  0.5 db. (Both measurements refer to an isotropic radiator). The gain of the target is taken as unity. This follows from the fact that Echo II is a predominantly spherical balloon 135 feet in diameter, hence it is large in terms of the wavelength ( $\approx$  6 inches) used in these experiments and the bistatic angles were less than 50 degrees. Under these conditions Echo II can be regarded as an isotropic scatterer and thus the target gain is taken as unity. The wavelength is taken as the corresponding to the center frequency of operation, 2260 mc. No correction is necessary for doppler shift since it is less than 100 kc and this shift represents a very small change in the wavelength.

The frequency stability of the transmitted signal was 1 part in  $10^6$ /days. The short-term (less than one second) stability was two orders of magnitude better. The two ranges,  $d_R$  and  $d_T$ , varied typically between 1000 and 4000 kilometers. The variation in the received power level due to changes in ranges is less than 30 db, typically from -163 to -140 dbw. The nomograph shown in Fig. 1 was prepared on the basis of Eq. (1), using the known parameters of the receiving and transmitting stations for quick calculation of received power level when the ranges are known. For example, for  $d_R$  = 1500 and  $d_T$  = 2500 kilometers the received power level is -71.5 - 75.8 -147.3 db relative to the one watt level on an Echo II path. Polarization effects, e.g., CP transmission, VP reception, were not included in the construction of the nomograph. In addition to the nomograph shown in Fig. 1, a small program is available for an IBM 1620 computer. The inputs to the program include the ranges  $d_R$ ,  $d_T$  as functions of time and the output; the received power level is in terms of db relative to the one-watt level. Figure 2 shows the plotted output of this program as a function of time for the passes analyzed in this report. Figure 2



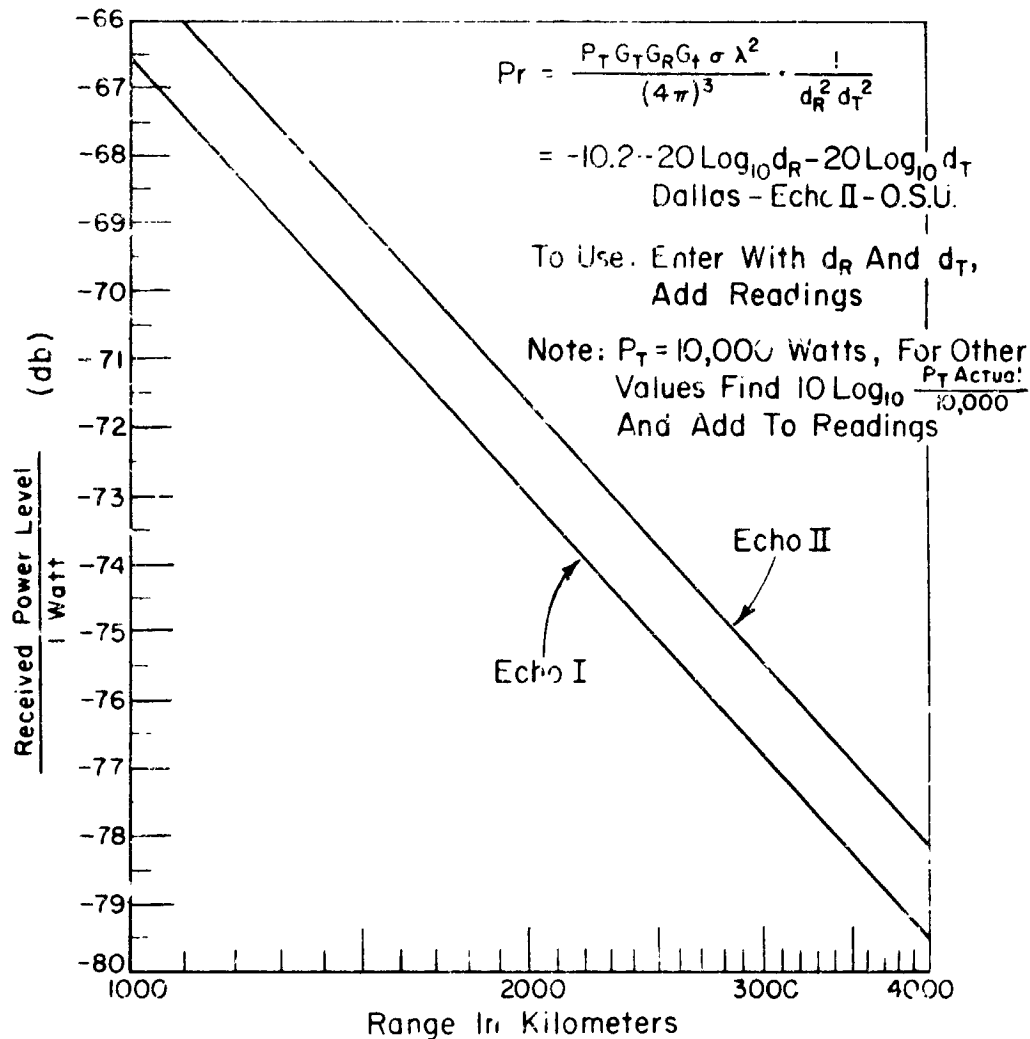


Fig. 1. A nomograph for quick calculation of received power level, Dallas - Echo - OSU link.

shows the actual received power, i. e., during these particular passes the transmitted signal was circularly polarized, but received with a linearly, (vertical) polarized antenna. To compensate for a polarization mismatch such as this it is necessary to subtract three db from the result obtained with the aid of Fig. 1.

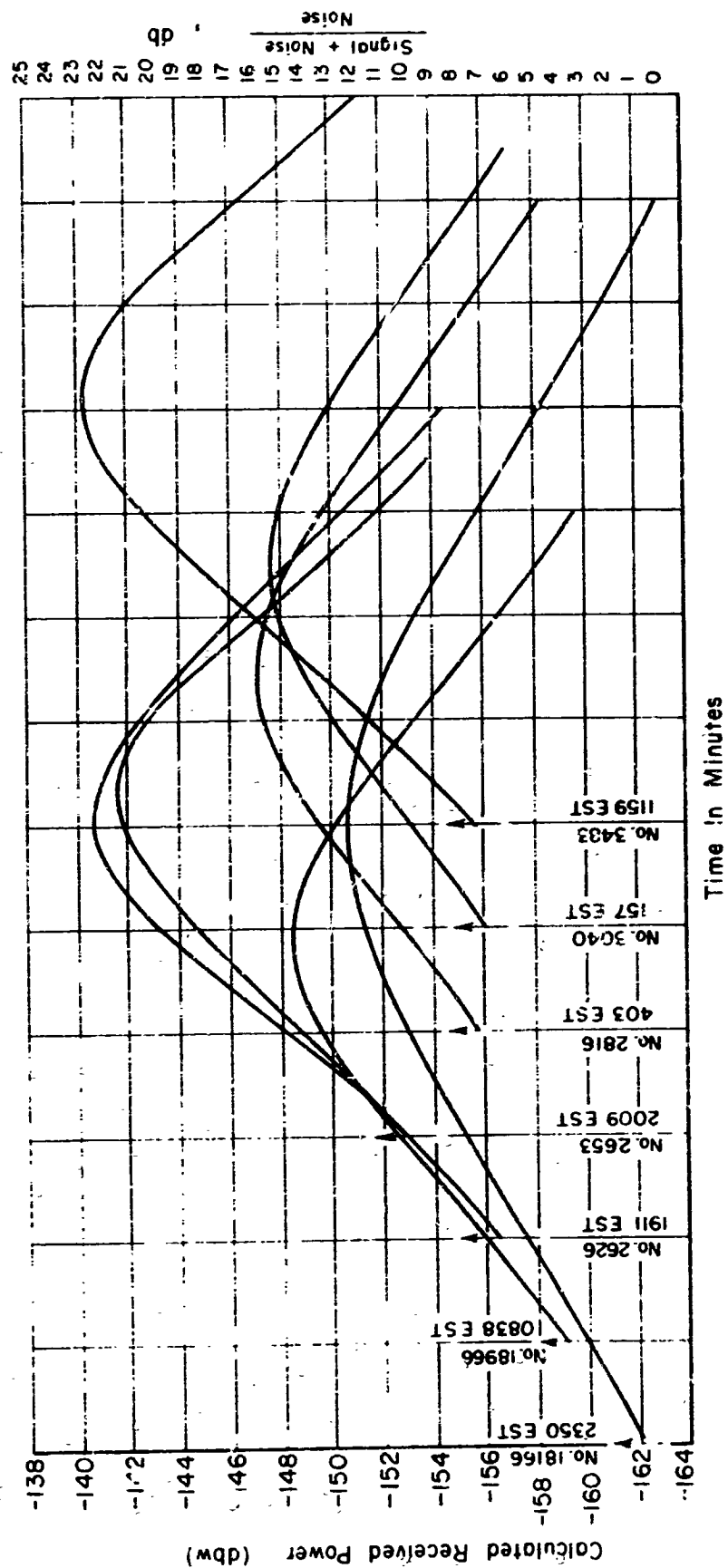


Fig. 2. Calculated received power level for some revolutions on Dallas - Echo - OSU link.

### III. MEASURED RECEIVED POWER

#### A. Instantaneous Received Power

The data indicating the instantaneous amplitude of the received signal were recorded in analog form on magnetic tape; for visual analysis the data were re-recorded on a chart recorder. Figure 3 shows the reproduction of this chart recording for revolution 2626. The horizontal lines are at three db intervals and the slanting line corresponds to the calculated received power level. The received power level is calculated on the basis of the best available measurements (estimates) of the values of system parameters. Figures 4 a-f show samples of instantaneous received power level recordings of Echo II revolutions 2653, 2816, 3040, and 3483, and from Echo I revolutions 18,166 and 18,966. The salient feature of these charts is that the instantaneous amplitude of the signal is apparently randomly fluctuating. The discrepancy between the actual received level and the calculated one can be  $\pm 10$  db or more. The precise measurement of the range of fading is limited by the maximum instantaneous signal strength and by the dynamic range of the receiver which is on the order of 20 db. It can be seen that the discrepancy between the two levels quite often is at least this entire dynamic range. The range of fading is usually associated with the surface roughness and in general increased range of fading indicates increased surface roughness. However, no such simple conclusion regarding the actual surface roughness can be drawn from these records. The effect of the surface roughness on the amplitude of the signal is greatly masked by the relative motion of the satellite. Were the satellite perfectly smooth and perfectly spherical, of course, there would be just a specular return from the flare spot on it without any diffuse components, regardless of what relative motion the satellite might have, including rotational motion. Also, no matter how rough the surface of the satellite may be, if it had no motion relative to the two sites of observation the returned signal would have a stable amplitude. Echo II is neither perfectly smooth, nor is it perfectly spherical; furthermore, on the basis of telemetry data it is claimed to be rotating in addition to the orbital motion. Hence, the presence of amplitude scintillation on the signal reflected by the satellite should always be expected. The purpose here is not to determine the surface roughness, but rather to present experimental data concerning the received signal strength and indicate the amount of variations in it. It is stated that the chief cause of these amplitude scintillation is the rough surface of the satellite and its relative motion.

From Figs. 3 and 4 it is evident that amplitude scintillations are continuously present on the signal. It is also evident that the magnitudes of these oscillations are as much as 10 db. To better evaluate the depth

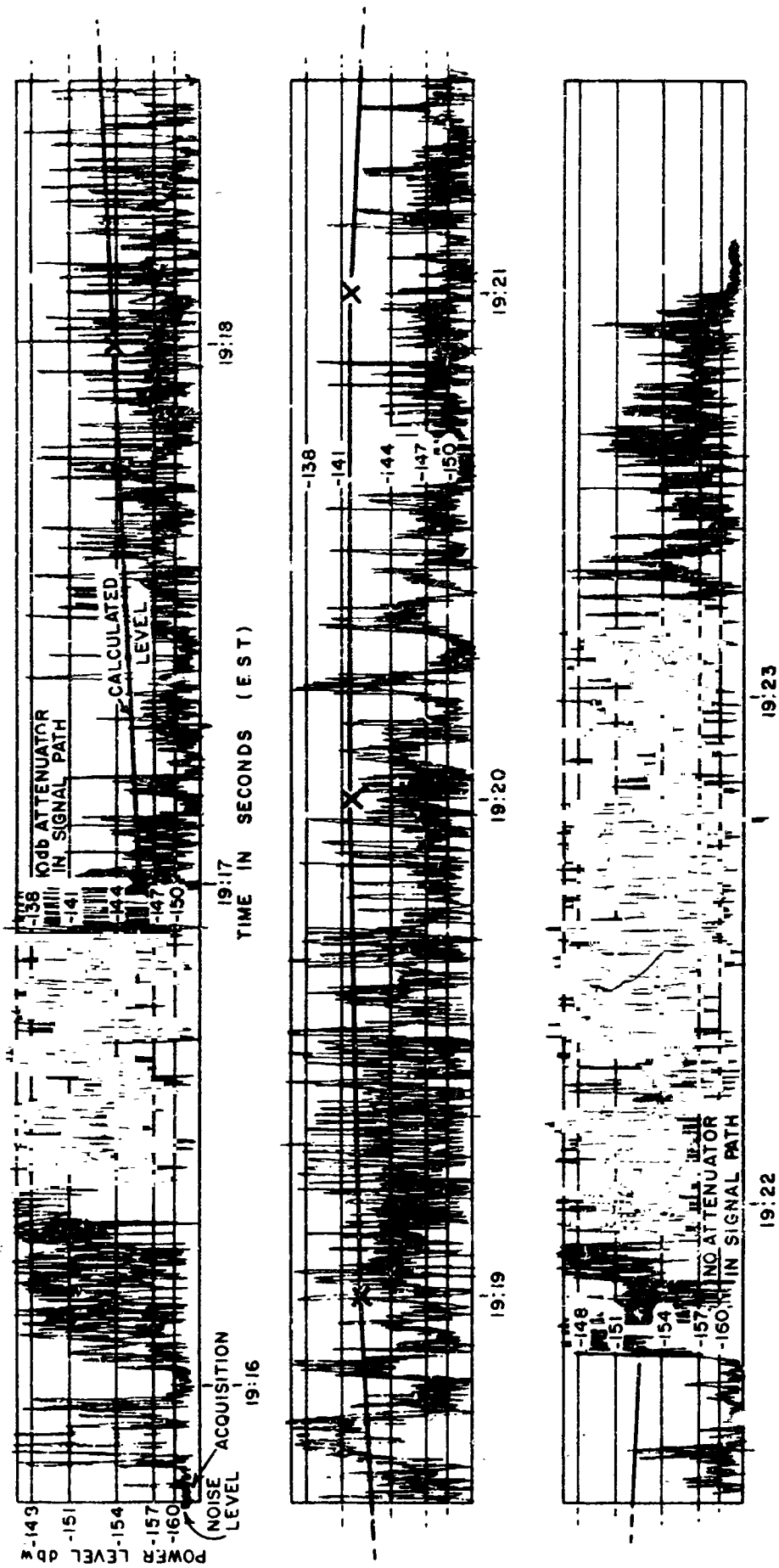


Fig. 3. Instantaneous received power level -- Echo II revolution 2626.

of fadings a one-minute period from the recording taken during revolution 2816 has been re-recorded at 10 X the speed shown in Figs. 3 and 4. (The response of the recorder extends up to 70 cycles). This fast recording of the instantaneous received power level is shown in Fig. 5. Again grid lines at three db intervals and the calculated power level are shown on the data. It can be seen from this figure that during the selected one-minute interval it is not possible to find a one-second period during which the received power level fluctuates less than three db. However, many one-second periods can be found where the amplitude of the signal practically oscillates between the saturation and the noise level. These two extremes indicate peak-to-peak amplitude scintillation of at least 20 db. It can also be seen from this fast recording, as well as from Figs. 3 and 4, that the received signal level is not necessarily below the calculated one but it can exceed that by as much as 10 db. While the aggregate of the receiver and transmitting system parameters is not known to an accuracy of a fraction of a db, it is safe to assume that none of the parameters change so rapidly as to cause large enhancements several times per second, and certainly there are no 10 db variations present at any time in either system. It is unlikely that some irregularities in the propagating medium are causing this enhancement because the frequency of 2 kmc/sec is such that ionospheric effects are no longer significant and atmospheric effects do not yet prevail on a large scale.<sup>2</sup> However, surface irregularities on the balloon, such as large scale indentations encompassing several areas of the sphere and acting like a corner reflector, or flat areas spreading over several sections could be responsible for signal enhancement.

To substantiate the above statement, which at best can be regarded as intelligent speculation, assume that one gore which is four feet wide at the equator is flat, i. e., it has a very large radius of curvature over a 4' X 4' area. The scattering cross-section of a flat plate is approximately

$$(2) \quad \sigma = 4\pi \left( \frac{A \cos \theta}{\lambda} \right)^2 ,$$

where

$A$  = the area of the plate,  $m^2$  ,  
 $\lambda$  = Wavelength, meters;

and where  $\theta$  is measured from the normal to the plate to the direction of incidence. Assuming  $\theta = 30^\circ$ , corresponding to an included angle of

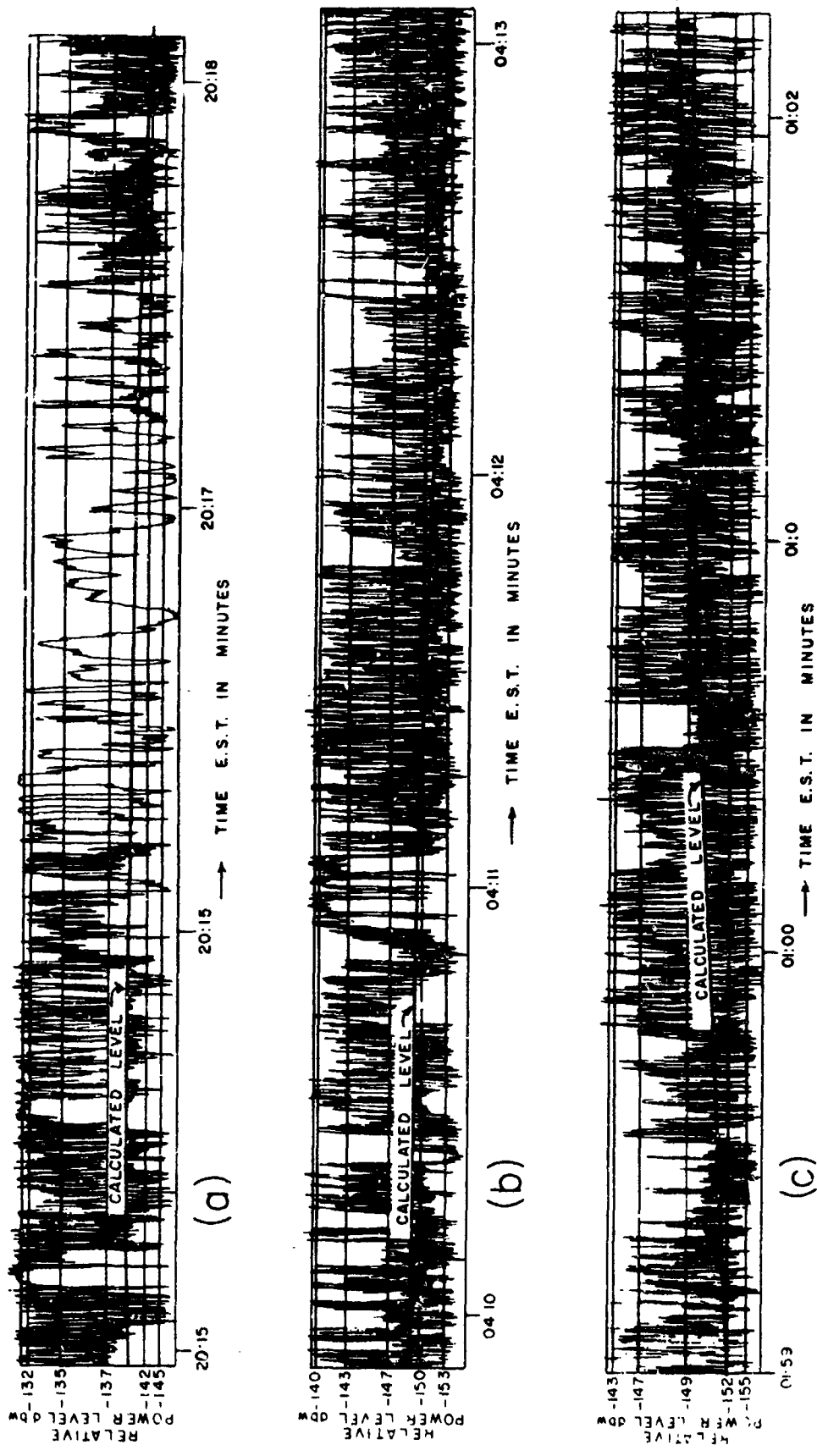


Fig. 4. Samples of instantaneous received power level from Echo II revolutions 2653, 2816, and 3040. (Curves a, b, and c, respectively).

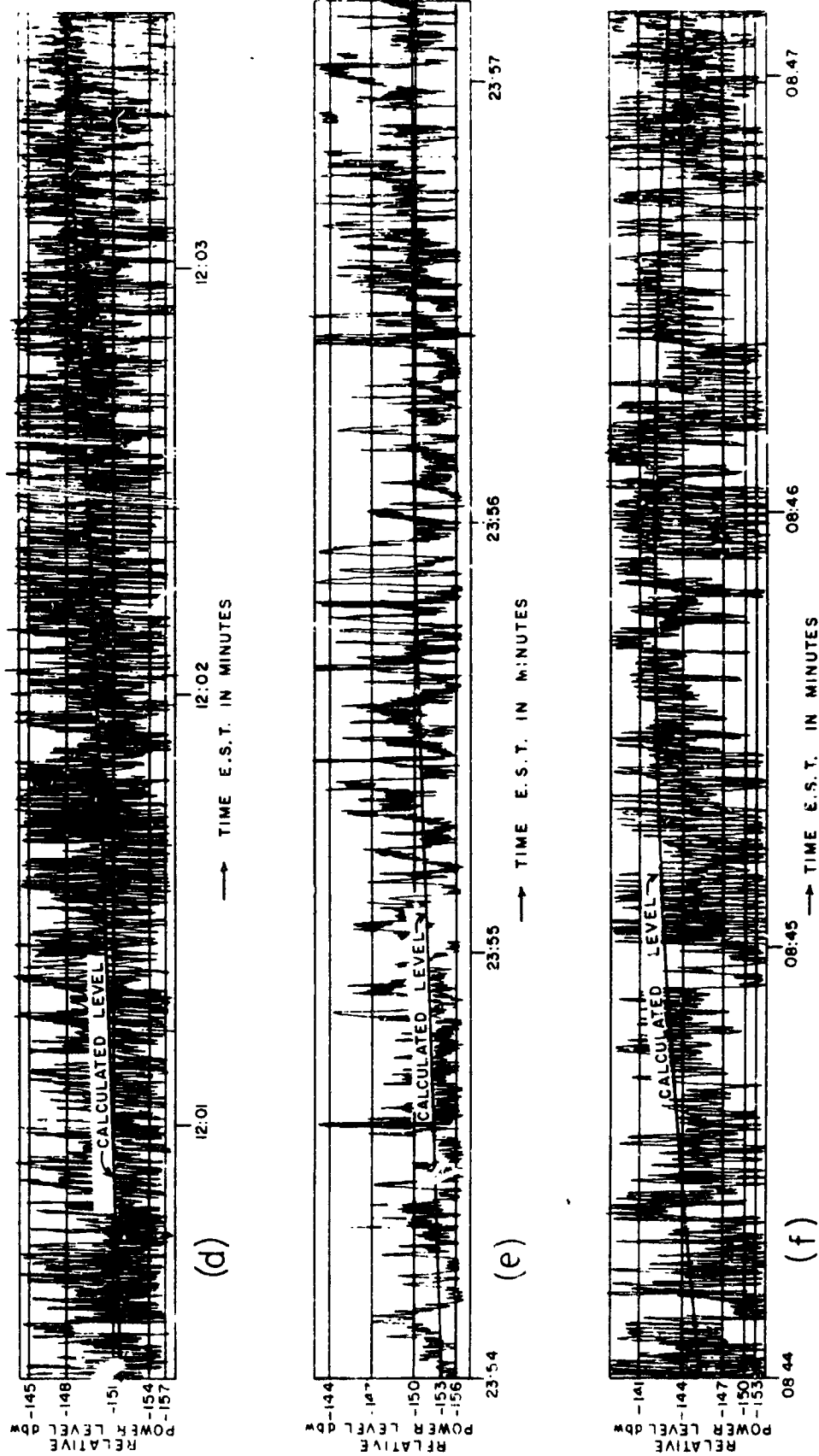


Fig. 4 Samples of instantaneous received power level from Echo II  
revolution 3483, and from Echo I revolutions 18,166 and  
18,966. (Curves d,e, and f, respectively).

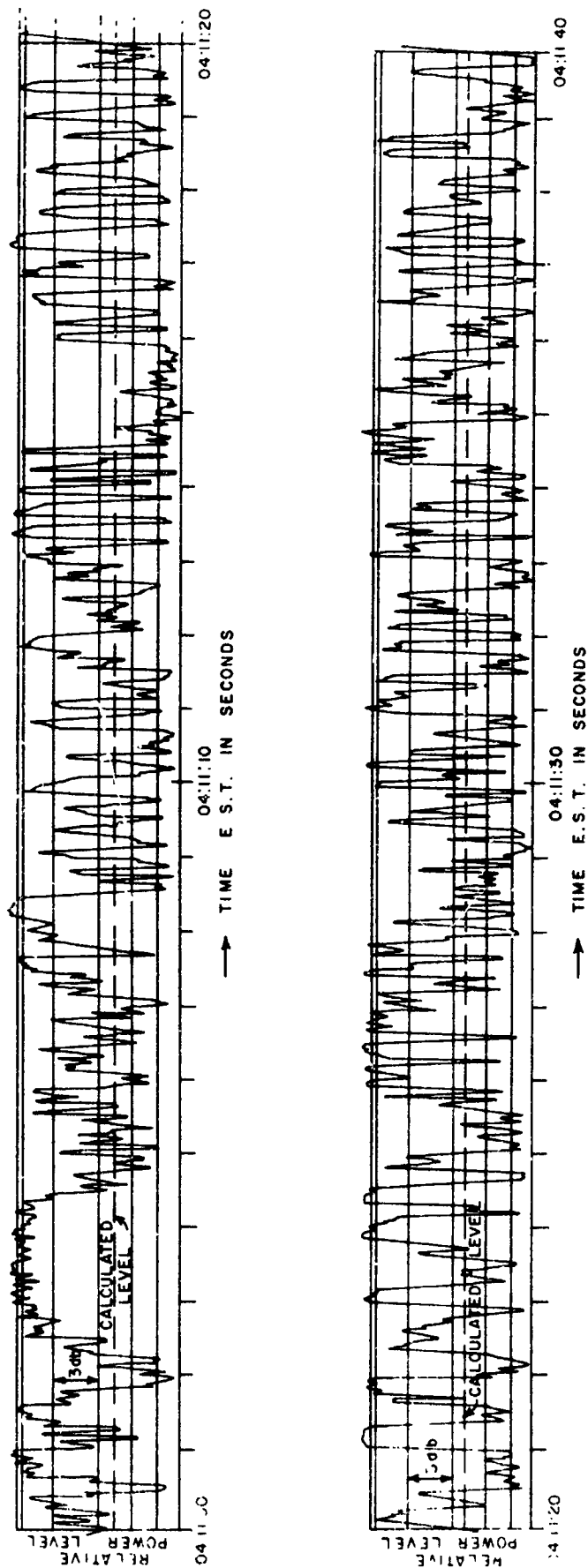


Fig. 5. Fast recording of instantaneous received power level -- Echo II  
revolution 2816, 04:11:00 to 04:11:40 EST.



$60^\circ$  in the bistatic case; and  $\lambda = 13.3$  cm, corresponding to the frequency of operation 2260 MC/sec, one can calculate the scattering cross section of the assumed flat area as:

$$(3) \quad \sigma = 10 \log_{10} 4\pi \frac{(4 \times 0.3 \cos 30^\circ)^2}{0.133} = 10 \log_{10} 770 \approx 29 \text{ db.}$$

The 29 db figure in Eq. (3) indicates that a suitably oriented flat area of dimensions  $4\lambda \times 4\lambda$  on the surface of the satellite would have a scattering cross section almost as large as the scattering cross section of the entire Echo II. A scattering cross section of about 10 db corresponds to a flat square area of about 16 inches on the side or about  $3\lambda \times 3\lambda$ :

$$(4) \quad 10 \log_{10} 4\pi \left( \frac{9\lambda^2}{\lambda} \cos 30^\circ \right)^2 = 10 \log_{10} 4\pi (1.1)^2 \approx 11 \text{ db.}$$

It is interesting to point out that this  $3\lambda \times 3\lambda$  area is some  $0.16 \text{ m}^2$  and the total surface area of Echo II is some  $5300 \text{ m}^2$ .

It is known from static inflation tests that under the proposed inflation conditions for Echo II amplitude scintillations in the reflected signal were on the order of 3 db peak-to-peak at S-band frequencies. From the fact that received signal scintillations greatly in excess of 3 db have been very frequently observed it is concluded that the balloon is not a perfectly smooth sphere, or at least it is substantially different from the shape it presented under controlled laboratory conditions, under which the static inflation tests and the associated reflected signal measurements were carried out.

It can be seen from Fig. 5 that the instantaneous signal strength level is predominantly above the calculated level. It was pointed out above that the calculated level is a function of the system parameters. Receiving system parameters can and have been checked repeatedly; the parameters of the transmitting site were obtained from published data and by private communication with personnel at the Dallas site. The calculated level and the calibration on the chart recordings in db steps were established by two methods: (1) by calculating the sensitivity of the system on the basis of the narrowest bandwidth ( $\sim 10$  kc) in the system and assigning the sensitivity threshold level (i.e., -163 dbw) to the deflection caused by the noise with the antenna pointed to zenith; and (2) by injecting a voltage of known and variable amplitude at the 30 MC IF frequency into the receiver and measuring the gains and losses

between the feed and the receiver. The two methods usually yield two different values; the difference between them is 1-2 db. Values for the transmitted power and transmitting antenna gain were based on the best available data at the time. These are the reasons for including Fig. 6, which is a fast recording of instantaneous received power level obtained during Echo II revolution 2626. The characteristics of this signal strength recording is apparently no different from the one shown in Fig. 5. There seems to be no significant change either in the rate or in the amplitude of the fluctuation. It is seen that trace reverses direction several times in a one-second interval and fluctuations between the noise and the saturation level are quite common. Again as in Fig. 5, it would be quite difficult to single out a one-second period during which the peak-to-peak fluctuations did not exceed 3 db. However, the calculated signal level in this particular case is predominantly above the measured level. This is in agreement with previous data<sup>1,4</sup> which indicate that the observed scattering cross section of Echo II on S-band and L-band frequencies is apparently one-half as large as the calculated  $1330 \text{ m}^2$ . From the data available it is not possible to conclusively establish whether Echo II is still predominantly smaller in apparent scattering cross section (on the basis of recordings which show that the calculated level is above the measured levels, such as in Fig. 6) or whether there have been some changes in the surface of Echo II causing an increase in the received signal level (on the basis of recordings which show that the calculated level is below the measured levels such as in Fig. 5). However, it is noted here that the present data from revolutions 2000 to 3500 are not always in agreement with previously reported findings. It is found that the measured signal level can exceed the calculated signal level when this latter level is based on the best available measurements (estimates) of the receiving and transmitting system parameters.

The sample of signal strength recording taken during revolution 2653 appears to repudiate all that has been stated above about the depth of fadings and about the frequency with which the fadings occur. From Fig. 4a it can be seen that during this particular revolution the fading rate became increasingly slower until there were about one or less maximum and minimum per second. In fact, in contrast to all other samples of signal strength recordings the received signal amplitude appears to be relatively stable. This phenomenon has been observed before in a quasi-monostatic, included angle of less than 10 degrees, scattering configuration. It is known that during this same revolution (2653) Collins' Facility and the Naval Research Laboratory's Facility of Stump Neck, Maryland, observed the same phenomenon at approximately the same time. It is thus safe to assume that the reason for these extremely slow fades is extraneous to the transmitting and receiving equipment.

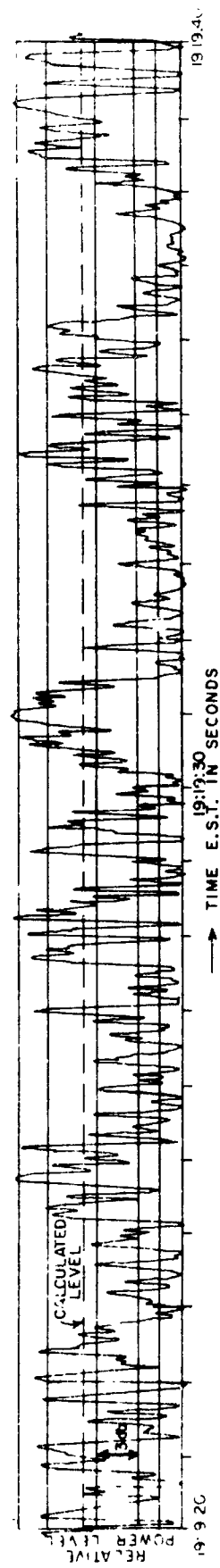
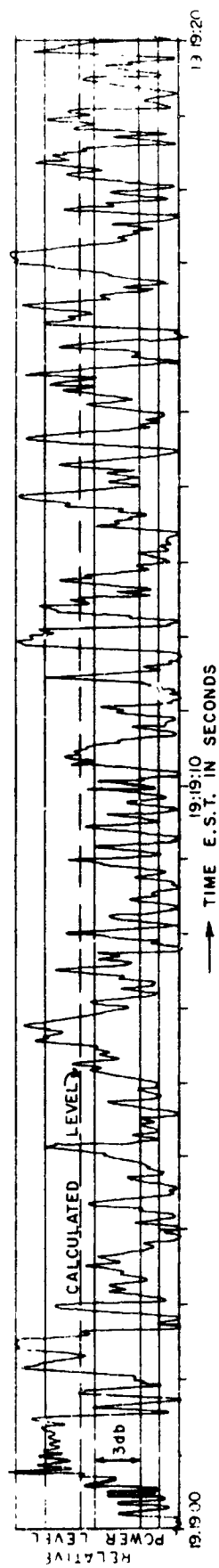


Fig. 6. Fast recording of instantaneous received power level -- Echo I  
revolution 2626, 19:19:00 to 19:19:40 EST.

Since during the two occurrences observed the satellite was in completely different sectors of the sky it is not likely that some atmospheric or ionospheric effect would have been the cause. It is most likely that the cause of these slow fades was the relative motion of the satellite. This statement appears to be substantiated by the fact that in both instances the duration of the phenomenon was about two minutes. A plausible explanation could be found by accepting the conclusion (on the basis of the telemetry data) that Echo II is rotating with a period of some 100 seconds and then postulating that during the time when the slow fades occurred the line of sight to the satellite and its axis of revolution were approximately coincident. In such a configuration the observer would see all visible portions of the satellite to be rotating with the same velocity, hence there would be no doppler smear. This doppler smear at the frequency of 2260 mc/sec and in a configuration when the line of sight and the axis of rotation are at  $90^\circ$  is approximately 20 cps. The orientation of the axis of rotation of the satellite is currently under study.

Figure 4 includes samples of signal strength recordings which were obtained during Echo I revolutions 18,166 and 18,966. Echo I has not been tracked by Ohio State University either consistently or extensively. However, there are some data at the disposal of the author from which these two passes were selected as representative ones. The depth of fades which occur on an Echo I link are not unlike the ones observed with Echo II. The level of the received signal strength is continuously fluctuating. The maximum fluctuations cover the entire dynamic range of the receiver (20 db). The level of the received signal can be below or above the calculated level by as much as 10 db. The fading rates, especially during revolution 18,166, appear to be slower than those occurring on an Echo II link; however, a more accurate comparison will be made on the basis of the power spectral density curves obtained from the two signals. Thus, it can be said that on the basis of the appearance of the signal strength recordings the two Echo satellites appear to be at least similar.

It is concluded that on the instantaneous basis the received signal level on an Echo link is a strongly time-dependent quantity where the time must be defined within a fraction of a second. There are practically no "relatively quiet" periods during which the signal level would fluctuate less than three db. The depth of fadings is in excess of 10 db; several times in a one-second interval it can be as large as 20 db. No attempt is made in this report to arrive at the rate of fadings; this question which is the subject of another report, is better treated in terms of the power spectra of the signals.<sup>5</sup> It appears, however, that the frequency associated with the large fadings (fadings that are in excess of 10 db)

are less than 10 cps. Rapid fluctuations, on the order of the frequency response of the recorder (70 cps.), can also be observed, but the amplitudes of these, as determined independently from oscilloscopic observations and also from oscillographic recordings are less than one decibel. Furthermore, these rapid fluctuations could be caused partly by the power line frequency. The appearance of the signal strength recordings, whether obtained during Echo I or Echo II revolutions is very similar, i.e., the magnitude of the scintillations and the frequency with which amplitude scintillations occur are practically the same for either satellite, indicating similar reflecting and scattering properties for the Echos. The very slow fading rates observed on some Echo II reflected signals probably originate from the apparent relative motion of the satellite.

#### B. Averaged Received Power

Since the instantaneous recordings of the received power level are not very suitable for comparison with calculated levels because of the large and rapid fluctuations, the data were re-recorded after passing through a low-pass filter whose time constant was 0.1 second. The effect of this smoothing operation can be seen in Fig. 7. The same time interval from revolution 2816 that was used for the fast recording was used for this integrated recording also. Figure 8 shows a similarly integrated ( $\tau = 0.1$  sec.) signal strength recording obtained during revolution 2626. The basis for selecting these two samples of signal strength recordings was to illustrate the deviations in the measured power level relative to the calculated level. In case of revolution 2816, the measured signal level is predominantly above the calculated level. On occasion this condition of excessive signal seems to prevail for several seconds. If the simple explanation given above for the increased signal in terms of assumed flat surfaces is accepted as at least plausible, then it appears that, on basis of Figs. 7 and 8, these flat surfaces are probably quite numerous and bunched together so as to provide an enhancement in signal return in spite of the relative motion of the satellite. A simple analogy of these assumed flat surfaces is the device seen in some dance halls, where a slowly rotating sphere is hung from the ceiling and is illuminated with multicolored lights. The surface of the sphere is studded with hundreds of small flat mirrors which reflect the colored lights in many directions. It is possible for a swiftly moving dancer looking at the sphere to see the same relatively intense reflection of the illuminating light for much larger period than could be observed by a relatively slowly moving one. This analogy, of course, is an optical one and is used here only as an illustration for a possible surface characteristic of the reflective satellite to help account for the apparent enhancements in the measured signal levels.

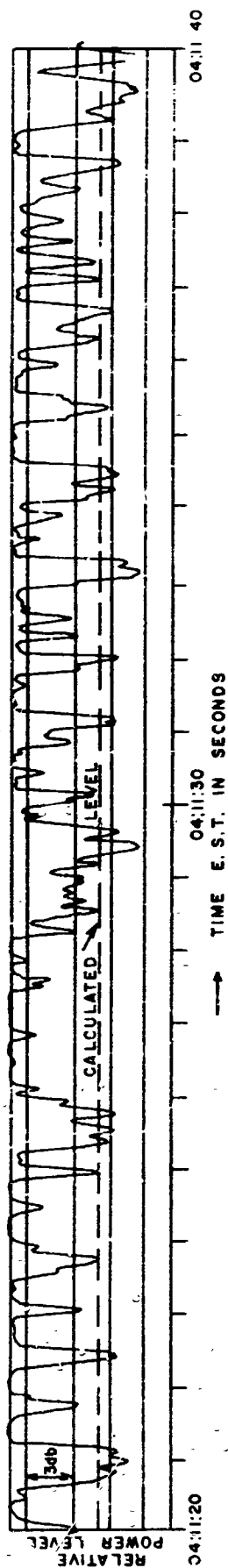
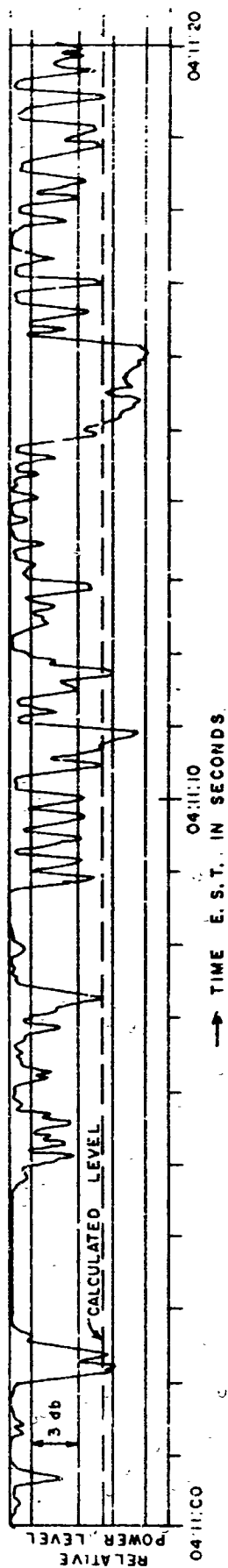


Fig. 7. 0.1-second averaged received power level recording -- Echo II revolution 2816, 04:11:00 to 04:12:00 EST.

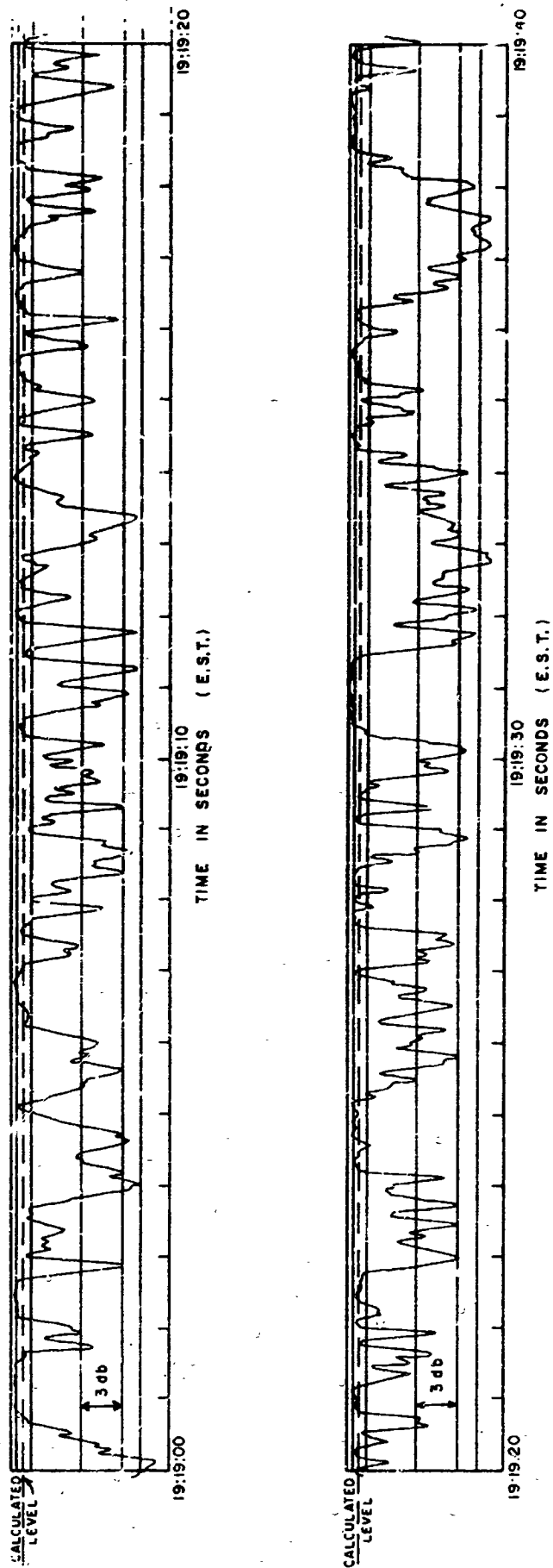


Fig. 8. 0.1-second averaged received power level recording -- Echo II revolution 2626, 19:19:00 to 19:19:40 EST.

In case of revolution 2626 the measured signal level is predominantly below the calculated level. This situation has been reported previously.<sup>1</sup> Just as there is no simple explanation for the apparent enhancement exhibited in Fig. 7, there may be many causes contributing to the apparently low measured signal level shown in Fig. 8. Some of these may be depolarization effects due to surface roughness, and diffuse return of the signal rather than specular return.

It can be seen both in Figs. 7 and 8 that the large and rapid fluctuations have been filtered out and the entire trace is smoothed. Most of the amplitude fluctuations are in the order of 3-6 db; occasionally, say once every ten seconds, the dropouts reach 10 db; and less often the fadings are in excess of 10 db. This filtering process with time constant  $\tau = 0.1$  second shows that continuous variations in the signal level up to and more than six db are present even on that average basis.

#### IV. DESCRIPTION OF THE SYSTEM

##### A. Receiving Site

The receiving site is at the Antenna Laboratory of The Ohio State University in Columbus, Ohio. The station coordinates are  $083^{\circ} 02' 30''$  West longitude,  $40^{\circ} 00' 10''$  North latitude. The receiving antenna was one of the four 30-foot aperture diameter, solid-surface paraboloids useful for frequencies up to 15 kmc/sec. The receiving system consists of a low-noise mixer, IF amplifiers, and frequency and/or phase-tracking local oscillator preceded by a low-noise, solid-state parametric amplifier. The incoming signal of the final IF frequency of 455 Kc is applied to a phase-locked demodulator, the outputs of which are directly proportional to the modulation intelligence (AM, FM, or PM) present on the signal. A simplified block diagram of the receiving and recording system is shown in Fig. 9. A detailed description of Ohio State University's Satellite Communications Center has been given elsewhere.<sup>6</sup>

##### B. Transmitting Site

The signals originated at 2260 mc/sec as CW from the 60-foot aperture diameter installation of Collins Space Communication Facility, Dallas, Texas. A detailed description of this site, including block diagrams of the transmitting system, can be found in reference 3.



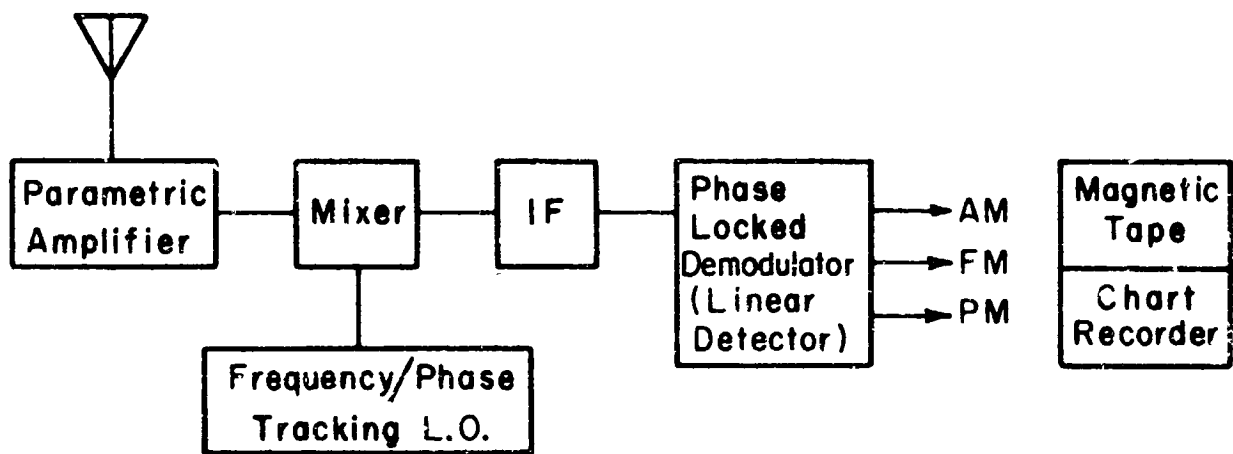


Fig. 9. Receiving and recording system.

## V. SYSTEM CALIBRATION

The measured power level is relative to the noise level of the system with no signal input. The calculated power level is based on the radar equation. The comparison between these levels was done by expressing the levels in terms of the signal-to-noise ratio,  $S/N$ . The noise figure,  $NF$ , of a receiver is given by the relationship

$$(5) \quad NF = \frac{N_R + N_i}{N_i},$$

where  $N_R$  and  $N_i$  are the noise components due to the receiver and the input noise, respectively. The input noise,  $N_i$ , is the product of the ambient temperature, Boltzman's constant, and the bandwidth:

$$(6) \quad N_i = T_{\text{ambient}} \times 1.38 \times 10^{-23} \frac{\text{joules}}{^{\circ}\text{K}} \times \Delta f.$$

Hence:

$$(7) \quad N_r = (NF-1)N_i = (NF-1)(270) \times 1.38 \times 10^{-23} \times \Delta f \text{ watts.}$$

One must consider, however, additional contribution from the antenna temperature. For convenience one can lump into the term "antenna temperature" the not-quite absolute zero sky toward which the main lobes of the antenna are directed (measurements of antenna temperature were carried out with the antenna pointing to Zenith); the back lobe pickup from the Earth at ambient temperature; possible celestial sources in the far side lobes; and losses in the transmission lines, switches, and connectors. The average value of the antenna temperature is  $100^\circ \text{ K.}^5$  Thus the noise power output at the receiver output is

$$(8) \quad P_N = N_R + N_A \text{ watts}$$

$$(9) \quad P_N = (NF-1)N_i + N_A = [(NF-1)270 + 100] 1.38 \times 10^{-23} \times \Delta f \text{ watts.}$$

The noise figure is 2.5 db and the narrowest bandwidth in the system is 12 kc. Substituting these values into Eq. (8), one obtains

$$(10) \quad P_N = [(1.78-1) 270 + 100] \times 1.38 \times 10^{-23} \times 1.2 \times 10^{-4} \text{ watts}$$

$$P_N = 10 \log_{10} [3.73 \times 1.38 \times 10^{-17}] = -163 \text{ dbw.}$$

The result given in Eq. (9) was used as the calibration level relative to which the measured power level was expressed as so many db above the noise level of -163 db.

Alternately, a voltage of known and conveniently variable amplitude was injected into the receiver at the 30 mc/sec IF frequency and the deflections on the chart recorder were observed as functions of the variations in the level of the input voltage. Then the gains and losses between the output of the RF feed horn and the 30 mc input to the receiver were measured and a given input RF power level was calculated for a given deflection which was caused by a voltage of known and variable

amplitude. This procedure resulted in a calibration scale which was within 1-2 db of the scale based on the sensitivity threshold of -163 dbw.

## VL ACCURACY OF MEASUREMENTS

### A. Antenna Gains

The calculated gain of the receiving antenna is 43 db; the measured gain is  $42.0 \pm 0.5$  db.<sup>7</sup> Several values are available for the gain of the transmitting antenna, ranging from 43.8 to 49 db. The latest available figure as of November 24, 1964, was  $47.1 \text{ db} \pm 1 \text{ db}$ . It was this  $47.1 \pm 1$  db value which was finally used in all calculations. The maximum error resulting from the best determined gains of the antennas is taken as  $\pm 1.5$  db.

### B. Transmitting Power

The transmitted power was on the order of 10,000 watts, as measured at the output of the final amplifier stage. Transmission line losses were about 1 db. It was learned that there were no appreciable fluctuations in the transmitted power level during the satellite pass, however, the aggregate of the inaccuracies in the measured power level and transmission line losses amounted to  $\pm 1$  db. This is the figure that is taken as the maximum error resulting from this source.

### C. Bandwidth and Gain of the Receiver

Because of the narrow-band tunable transistor amplifier circuits in the receivers, it was necessary to check both the tuning and the bandwidth of these stages and the gain of the receiver prior to each pass. It has been found that both the bandwidth and the gain varied from pass-to-pass, however it was possible to measure the bandwidth to an accuracy of less than one kilocycle and to adjust and maintain the gain for the duration of the pass to within one-tenth of one db. Thus, the error from these sources is  $\pm 0.2$  db.

### D. Noise Figure

The noise figures of the parametric amplifiers were checked prior to each pass, their gains and bandwidths adjusted if necessary. It was

found that the gains and bandwidths required adjustments every few hours; however, the noise figure as measured after the tuning procedure remained constant within  $\pm 0.1$  db, thus the error from this source is  $\pm 0.1$  db. However, the practice of assigning the -163 dbw level to the deflection caused by the noise, and the procedure of matching deflection caused by a signal and by the noise, could have led to an error of one db. Thus, the total error from this source is taken as  $\pm 1$  db.

#### E. Frequency Track

The local oscillator was either frequency- or phase-locked to the incoming signal whose stability is 1 part in  $10^6$ /day. The short-term stability was claimed to be at least two orders of magnitude better on the basis of measured drift of less than 20 cps during a typical pass of 15 minute duration. The special receivers used to derive an error signal for driving the antenna had a bandwidth of less than 5 Kc thus placing even more exacting requirements on the doppler tracking servo loop in the L.O. than the actual communication receivers. It was observed on countless occasions that when frequency- or phase-lock conditions occurred the signals were within the pass band of the tracking receivers whose center frequency was carefully lined up prior to each pass with that of the communication receiver, hence were well within the pass bands of these latter receivers; once the signal was lost the L.O. promptly coasted away several tens or hundreds of kilocycles. That is to say once tracking occurred the signal was very close to the center of the pass band and when the signal was not in the pass band, no tracking could occur. Thus, no error resulted from this source.

#### F. Mechanical Tracking

The mechanical tracking of the satellite was well within one-tenth of the beamwidth at both the transmitter and the receiver sites. Receiving antenna half-power beamwidth is  $\sim 1.2^\circ$ , transmitting antenna half-power beamwidth is  $\sim 0.6^\circ$ . Figure 10 shows a monopulse error signal recording. The vertical scale is 0.4 degrees between top and bottom of the chart, or 0.04 degrees per 5 millimeters. The total error from this source is, at most,  $\pm 0.1$  db.

#### G. Polarization Effects

It is reasonable to assume that Faraday polarization rotation effect is negligibly small. Depolarization due to the possible rough

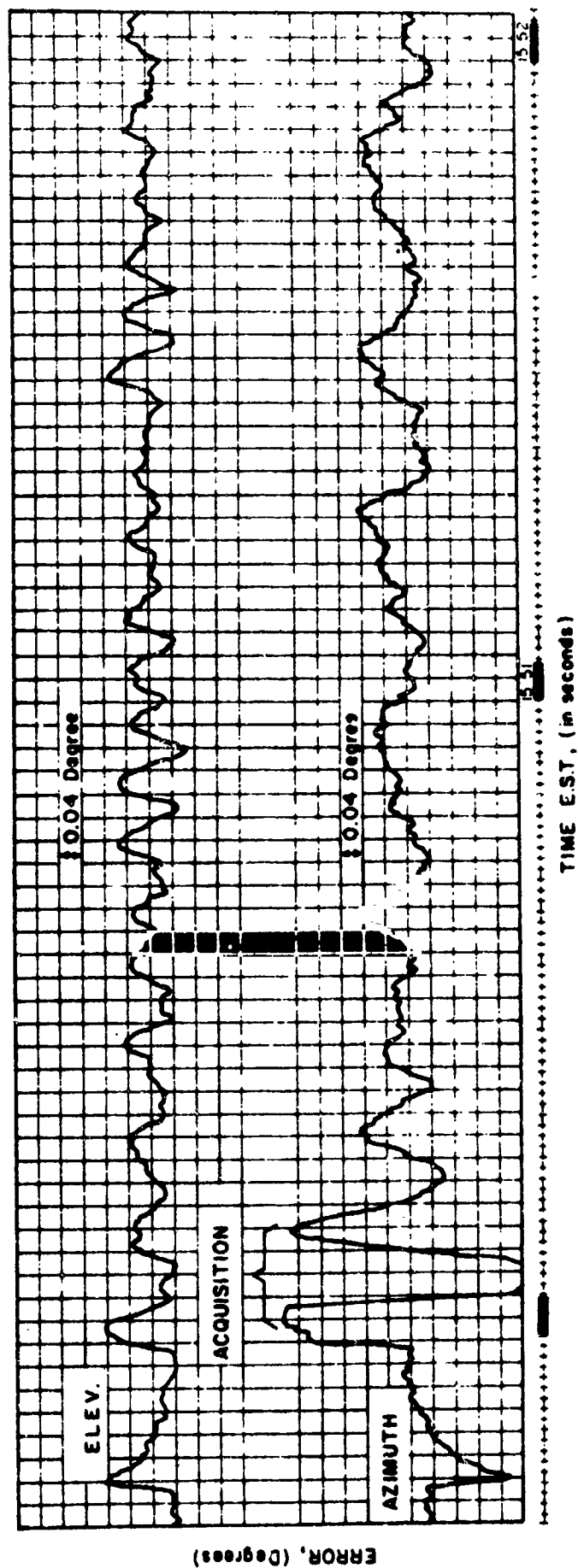


Fig. 10. A typical monopulse tracking error recording.

surface of the balloon is currently under study and is not considered in this report. The apparent polarization rotation due to changing path geometry is not applicable in this case since the transmitted signal was circularly polarized. At present there are no figures available on the axial ratio or ellipticity of the polarization at the transmitting antenna. It is assumed that outside of the three db loss due to VP reception of a CP transmitted signal there are no errors resulting from this source.

The following tabulation is presented as a summary on the accuracy of the measurements:

TABLE I

Antenna gain	Transmitter site	$\pm 1.0$ db
	Receiver site	$+ 0.5$
Transmitted power level		$\pm 1.0$
Bandwidth and gain of receiver		$\pm 0.2$
Noise Figure and Sensitivity Level		$\pm 1.0$
Frequency Track		$\pm 0.0$
Mechanical Track including both sites		$\pm 0.1$
Polarization Effects		$\pm 0.0$
Total of Inaccuracies		$\pm 3.8$ db

## VII. SUMMARY

This report presents a signal strength analysis of Echo II - re-  
flected signals during revolutions 2000 - 3500, from which five repre-  
sentative samples have been chosen. An analysis of two Echo I revolu-  
tions which occurred during the same time is also included for comparison.  
The signals at 2260 mc/sec originated from Dallas, Texas, as cw. An  
analysis on the basis of instantaneous signal strength recording and one  
on basis of averaged, smoothed ( $\tau = 0.1$  second) data have been carried  
out. From the instantaneous recordings it has been found that rapid,  
(several times per second) and deep fades of at least 20 db are more  
common than they were for the first 500 revolutions. On some occasions  
the fadings were so severe as to present an oscillation-like appearance  
as the signal strength varied several times per second between the noise  
and saturation levels. Relatively stable periods when the signal strength  
recording showed peak-to-peak amplitude scintillations less than three  
db were virtually non-existent. On repeated occasions very slow fading  
rates were also observed. These slow fades were attributed to returns

from an area that is near the polar region of the possibly rotating balloon. It has been found, on the basis of averaged data, that after a 10 cps low-pass filter the fluctuations still are on the order of 10 db with continuous fluctuations of about six db peak-to-peak. Both in the instantaneous and in the averaged data extended periods have been found during which the received signal strength was below the calculated one, and also when the measured level exceeded the calculated one. Discrepancies as large as 10 db have been noted for a period of at least one minute. Measured signal strength below the calculated one is in agreement with previous findings, however there is no ready explanation for excessive signals lasting for periods of minutes. The findings are based on the best available measurements from the receiving site and the best available measurements and/or estimates from the transmitting site.

The general appearance of signal-strength recordings of Echo I- reflected signals indicate that the returns from the two satellites are very similar. The peak-to-peak amplitude scintillations and their rates are of the same character on signals reflected by either satellite.

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## REFERENCES

1. Zolnay, S. L., "An analysis of Echo II reflected Signals at 2 KMC/sec," Report 1072-9, TDR II - Vol. I, July, 1964. Antenna Laboratory, Ohio State University Research Foundation; prepared under Contract Number AF 30(602)-2166, Rome Air Development Center, Research and Technology Division, Air Force Systems Command, USAF, Griffiss Air Force Base, New York.
2. Zolnay, S. L., "A Study of Scintillations at 2 KMC/sec Utilizing Solar Radio Emission," Report 1072-5, 17 August 1962, Antenna Laboratory, Ohio State University Research Foundation; prepared under Contract Number AF 30(602)-2166, Rome Air Development Center, Research and Technology Division, Air Force Systems Command, USAF, Griffiss Air Force Base, New York.
3. Experiments Plan Passive Communications Satellite Echo II, Project Manager, H. L. Eaker, Goddard Space Flight Center, NASA, Greenbelt, Maryland, 1 January 1964.
4. Julian, R. F., and Hynek, D. P., "Cross-Section Measurements of the Echo II Satellite by the Millstone L-Band Radar," Group Report 1964-16, 7 April 1964, MIT Lincoln Laboratory, Lexington, Massachusetts. Prepared under Electronic Systems Division, Contract Number AF 19(628)-500.
5. Zolnay, S. L., "Power Spectral Density of Echo II Reflected Signals," Report 1878-5, January, 1965, Antenna Laboratory, Ohio State University Research Foundation; prepared under Contract Number NAS5-9507, National Aeronautics and Space Administration, Goddard Space Flight Center, Glen Dale Road, Greenbelt, Maryland.
6. Eberle, J. W., "An Adaptively Phased, Four-Element Array of Thirty-Foot Parabolic Reflectors for Passive (Echo) Communication Systems," IEEE, PCAP, March, 1964.
7. Hayes, D. D., Report in preparation.